

NITROGEN FERTILIZER TECHNOLOGIES

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ABSTRACT

Controlled- and slow-release nitrogen (N) fertilizers have been commonly used in high-value applications, such as horticultural production. Traditional controlled-release products have not been economical for use in major grain crops because of high cost and low crop prices. New economical, controlled-release fertilizers are available for use in field crops such as corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and other commodity grains. Technology improvements have reduced manufacturing costs, while high N prices and interest in improved N-use efficiency have increased demand for new products. Polymer-coated fertilizers seem to offer the most promise. Nitrogen release from polymer-coated fertilizers is by temperature-controlled diffusion. Coupling N release with soil temperature, a primary factor in crop growth rate and N demand, allows N release to be programmed to better match crop needs. Research shows that controlled N release improves crop output per unit of applied N and reduces N losses.

INTRODUCTION

Nitrogen-recovery efficiency for cereal production worldwide has been estimated at only 33% (Raun and Johnson, 1999). Some of the N not used by the crop is presumed lost through denitrification, runoff, volatilization, and leaching. Such losses raise concerns about water contamination and greenhouse gas emissions. Low use efficiency of fertilizer N also reduces economic returns from fertilizer inputs. Nitrogen-use efficiency can be improved by reducing N losses (Englesjord et al., 1997). New fertilizer products – controlled-release N fertilizers or CRN – that release N at controlled rates to maintain maximum growth and minimize losses have been developed in the last two decades (Goertz, 1991; Hauck, 1985; Waddington, 1990). Increased efficiency can also increase yield and quality of crops and economic return for growers.

Controlled or slow-release fertilizers can be classified in two basic groups: compounds of low solubility and coated water-soluble fertilizers. Other products, known as N stabilizers or bio-inhibitors, are not true slow-release products, but reduce N losses by slowing N transformations. Polymer-coated controlled-release fertilizers look promising for widespread use in agriculture because they can be designed to release nutrients in a more controlled manner. The polymers are generally durable and exhibit consistent release rates that are predictable when average temperature and moisture conditions can be estimated. Nutrient release rate is altered by manipulating properties of the polymer coating. A more detailed review was provided in Hauck, (1985). Some salient points from that review are described below.

Bio-inhibitors are generally either nitrification or urease inhibitors. Two nitrification inhibitors sold commercially in the United States are nitrapyrin (1-chloro-6-(trichloromethyl)pyridine) and DCD (dicyandiamide). Nitrification inhibitors can improve N-use efficiency and yields when nitrification leads to N loss. Nitrapyrin, first sold in 1976, is used primarily with anhydrous ammonia, but may be used with liquids injected into soil. Dicyandiamide, introduced

in the U.S. in 1984, is used with dry and liquid fertilizers. Nitrification inhibition generally ranges from a couple of weeks to a few months depending on soil temperature and moisture.

Fertilizers delaying N release through reduced solubility include both inorganic salts and sparingly soluble organic compounds. The latter group constitutes most of the commercial CRN fertilizers available in the U.S. Magnesium ammonium phosphate, first proposed for use in 1858, is an example of a slowly soluble inorganic N salt. Most sparingly soluble organic N fertilizers are urea-aldehyde reaction products. They typically contain about 30-35% N and decompose in soil by chemical and/or biological processes. Solubility and N release are varied by altering the length and cross-linking of the urea polymers. Ureaform, first patented in 1924 in Germany, was first commercially produced in 1955. Another common product, isobutylidene diurea (IBDU), regulates solubility and N release by particle size and surface area.

The most common coated slow/controlled-release fertilizers are sulfur- and polymer-coated products. Sulfur-coated urea was first produced in 1972. Sulfur-coated urea releases N by biological oxidation of the S coating, physical rupture or fracture of the coating, and diffusion thru the somewhat porous S coating. It is commonly used in turf formulations.

Polymer-coated fertilizers were manufactured as early as 1970 in Japan. A variety of polymers are used to form semi-permeable coatings on soluble N sources, usually urea. Release is regulated by polymer chemistry, coating thickness, soil moisture, and soil temperature. Because of high cost, CRN use in agriculture is limited, accounting for less than 1% of worldwide fertilizer consumption (Englesjord et al., 1997). Recent advancements have decreased production costs to an economical level for commodity grain crops.

There have been limited published studies of the value of CRN on large acreage agricultural crops. The studies generally indicate there is significant value in using CRN under most conditions. Howard and Oosterhuis (1997) showed that N application rates on cotton may be reduced by 40% when CRN is used. Trials using CRN on winter wheat indicated a 20% yield increase compared with growers' standard practice; research on potatoes (*Solanum tuberosum* L.), onions (*Allium cepa* L.), and garlic (*Allium sativum* L.) also showed an increase in yield and quality with CRN (Tindall and Detrick, 1999). In potatoes, CRN produced less nitrate leaching, greater fertilizer-N recovery, and greater marketable yields than split applications (Zyomuya, 2003). In western Canada, fall application of polymer-coated urea on barley resulted in decreased nitrate accumulation and fertilizer-N loss, while spring application of polymer-coated urea increased crop N uptake (Nyborg et al., 1993).

Potential for CRN use in North America and Europe is high if cost can be reduced and benefits consistently demonstrated. Adoption will be most rapid where N loss is large, in-season N applications are common, and in crops with shallow root systems. In the U.S. Corn Belt, much of the required N is applied in advance of crop uptake. Winter and spring precipitation in this geography often exceeds evapotranspiration, and N-loss potential is high (Balkcom et al., 2003). CRN use can significantly improve N use-efficiency in these production systems.

This paper will review results from a large number of studies conducted in the U.S. Corn Belt from 2000 to 2003. The studies constitute comparisons of CRN with a variety of conventional N fertilizers and application practices on commodity grain crops. The results summarized represent both small-plot studies and field-scale grower trials over a wide range of environments. The objectives of the studies were to demonstrate improved N-use efficiency and crop productivity and CRN suitability for commodity grain crops.

METHODS

This paper uses corn studies as examples of CRN's potential for commodity grain crops. Corn responses to CRN were evaluated by comparison with similar applications of conventional N sources in many soil and weather conditions. Controlled-release N applications were most commonly applied as a single pre-plant treatment. Conventional N applications included pre-plant, side-dress, and split applications. Data from replicated plot studies and grower field trials are pooled together and subjected to two analyses. The first analysis evaluates all comparisons of pre-plant CRN with pre-plant applications of conventional N fertilizers at the same N application rate. In studies with multiple N rates and products, each rate-product combination is considered as a single comparison. We classified the data by the magnitude of yield increase and determined the frequency in each yield-increase range.

The second analysis consists of comparing the relative yield response to conventional N sources with the response to CRN. Relative-yield responses were modeled as quadratic-response-and-plateau (QRP) responses using SAS PROC NLIN (SAS Institute, 1996). QRP models were parameterized for all data combined and for comparisons with urea and urea-ammonium nitrate solution (UAN) individually. There were insufficient comparisons with ammonium nitrate (NH_4NO_3), ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$), and anhydrous ammonia (NH_3) to accurately model response to those products individually.

RESULTS AND DISCUSSION

Controlled-release N produced greater yields in the majority of comparisons when applied pre-plant at the same N rate as pre-plant applications of conventional N sources (Figure 1). The data represent both responsive and non-responsive sites. Yield increases in excess of 24 bu/acre generally coincide with conditions conducive to high N-loss potential, although N loss was not measured in these studies. Over all trials, pre-plant CRN increased corn yields by about six bu/acre over other pre-plant N sources at equal N rates (Table 1).

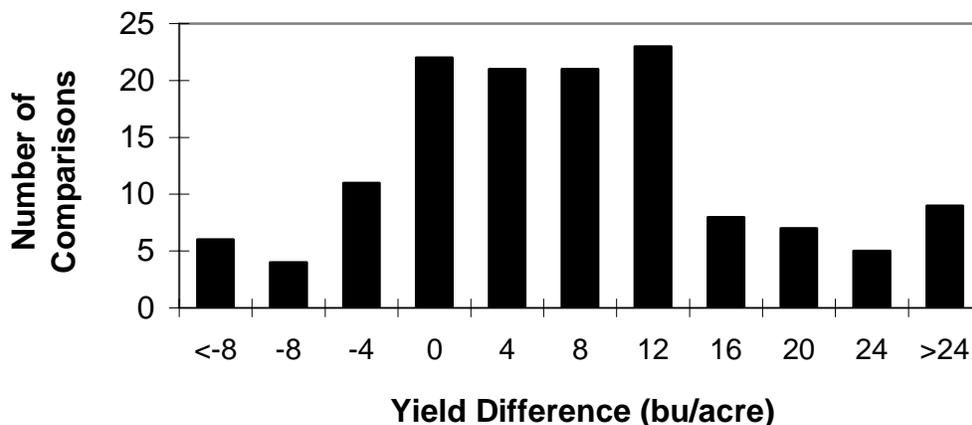


Figure 1. Frequency distribution of corn-yield response in comparisons of pre-plant CRN with pre-plant applications of conventional N fertilizers at equal N rates (U.S. Corn Belt, 2000-2003). Positive numbers denote greater yield with CRN than with conventional N sources.

Table 1. Summary statistics for comparisons of spring pre-plant CRN with pre-plant applications of conventional N sources at equal N rates.

Yield increase of (bu/acre)	< 5	5 to 10	>10	≥5	All comparisons
Comparisons in group	64	31	40	71	135
% of total comparisons	47.4	23.0	29.6	52.6	100.0
Group average yield increase (bu/acre)	-2.2	7.5	18.8	13.9	6.3

Some negative responses to CRN were observed, but there are few logical explanations for these observations. If the controlled-release properties of CRN offered no protection for N and did not increase N uptake or reduce N losses, then CRN would be expected to perform no worse than conventional N fertilizers. One possible explanation is that CRN did not release soon enough to meet plant needs. Our release data give no indication that this would occur and indicate N release from CRN applied before planting precedes plant demand. About 20% of responses less than five bu/acre and almost 40% of significant negative responses were observed in comparisons of surface-applied CRN with surface-applied NH_4NO_3 . Ammonium nitrate is considered non-volatile in most conditions. It is possible that some N was lost by ammonia volatilization from the urea as it diffused through the coating. Conversely, it is interesting to note that some of the largest yield increases observed with CRN were in comparison with surface-applied urea and UAN where volatilizing conditions were present.

Some growers and dealers prefer fall N application, usually as anhydrous ammonia, because of advantageous seasonal N pricing and heavy spring workloads, but it is discouraged because of potential for N loss during wet periods of winter and spring. In limited studies, fall-applied CRN out-yielded fall or spring applications of conventional N sources in some comparisons. Results of these comparisons indicate potential for fall CRN use, but data is insufficient to justify recommending fall CRN applications at this time. Until further testing is completed, fall CRN applications should be considered experimental, although CRN does appear to be superior to conventional N sources applied in the fall.

Side-dressing N and multiple N applications are recommended best management practices for reducing N losses. Controlled-release N has the potential to provide growers greater flexibility in timing and reduce costs by replacing side-dress and multiple applications with a single pre-plant application. In studies comparing pre-plant CRN with side-dress and split N applications, CRN out-yielded other applications by more than five bu/acre in about 54% of those comparisons. In some comparisons under extremely high loss potential, CRN yielded less than conventional split or side-dress applications. Under these conditions, N applied later would have less exposure to loss, while N released from CRN would have some exposure, although less than conventional N sources applied at the same time. Under extreme loss potential, split applications of CRN significantly out-performed split applications of conventional N.

Nitrogen-use efficiency is of interest in reducing environmental risk. Greater recovery of N by the crop allows the grower to produce the same crop at a lower fertilizer-N rate. Less N is therefore exposed to loss, and the grower is less likely to apply more than is needed. In order to evaluate relative N-use efficiency of CRN and conventional N fertilizers, we compared relative yield responses of CRN with other fertilizers (Figure 2). CRN achieved about 5% greater plateau yields than conventional N sources. Of greatest interest is the CRN rate that produces the same

relative yield as other N sources. All conventional N sources combined produced a relative yield plateau of 94% at 165 lbs N/acre. Controlled-release N produced 94% relative yield at 118 lbs N/acre, a savings of 47 lbs N/acre. When taken as a percentage of average N rates of 120 to 200 lbs N/acre, this equals a savings of about 39 to 24%, respectively. When N sources are evaluated individually, urea produced a plateau yield of 95% at 185 lbs N/acre (n=68) compared with 121 lbs N/acre for CRN in the same studies; UAN (n=49) produced a plateau yield of 93% at 160 lbs N/acre versus 98 lbs N/acre for CRN. The average savings for urea and UAN (63 lbs N/acre) equates to a savings of 53 to 32% of N rates from 120 to 200 lbs N/acre, respectively, without reducing average corn yields. These relative N savings are similar to improvements observed by Howard and Oosterhuis (1997) in cotton.

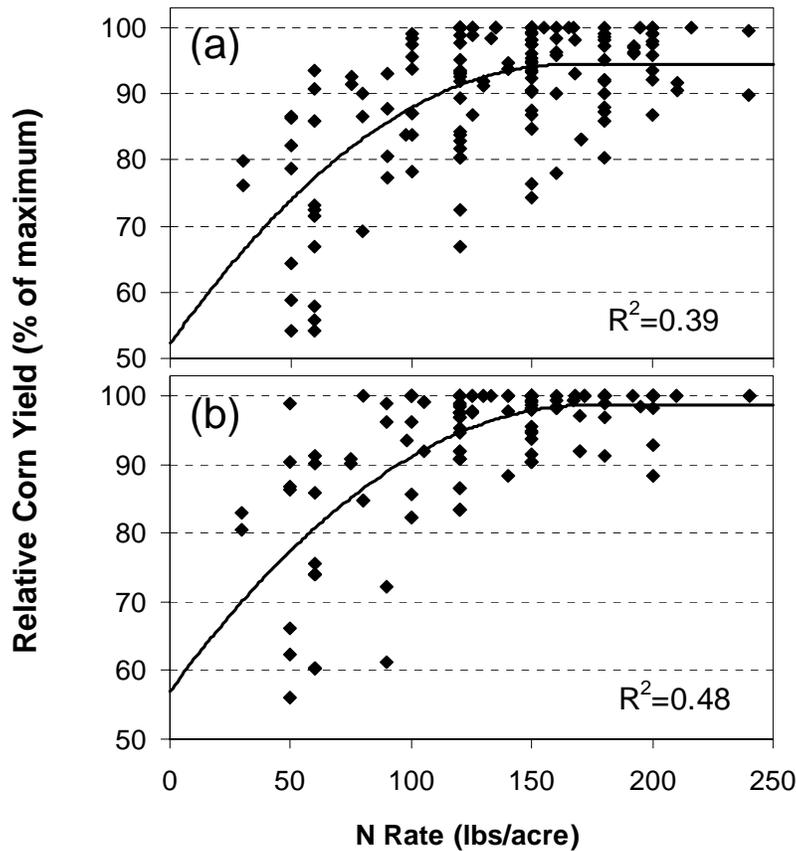


Figure 2. Relationship between relative yield (percent of the highest yielding treatment within an individual study) and rate of N applied. The plateau yield from the QRP model was 94% for conventional N (a) and 99% for CRN (b).

Performance of conventional N is more subject to variability in weather and soil conditions than CRN. Less variability was observed in corn-yield response to CRN ($R^2=0.48$, Figure 3b) than in response to conventional N ($R^2=0.39$, Fig 3a), especially at rates approaching or above the plateau yield. Differences in the variability of yield response (Table 1 and Figure 1) seem to indicate that when CRN does not out-perform other N sources, it is more frequently attributable

to greater-than-expected efficiency of conventional N than to poor performance of CRN. If N-loss potential is low, little difference among products would be expected.

SUMMARY AND CONCLUSIONS

Controlled-release nitrogen fertilizers have the potential to significantly improve N-use efficiency while maintaining crop productivity. Controlled-release nitrogen is demonstrated in these studies to be a more efficient nitrogen source for grain crops without sacrificing yields. When applied at the same rate as conventional N sources, CRN increased corn yields sufficiently to offset additional cost of the product – in most cases increasing grower profit – while reducing risk of N loss to the environment. It was also demonstrated that CRN can be applied to corn at significantly lower rates, conservatively 25 to 35% less, than conventional N sources without sacrificing crop yield.

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